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DOMESTIC WASTEWATER TREATMENT WITH EMERGENT HYDROPHYTE BEDS IN FRANCE

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ABSTRACT

CEMAGREF has been studying Emergent Hydrophyte Treatment Systems (EHTS) since 1983 on three experimental sites. Two of them can be considered as typical for the Max-Planck-Institute Process (MPIP) as developed by Dr. Seidel, regarding their general layout with the succession of five treatment stages in cascade planted with different Emergent Hydrophyte species. The performance of one of these two plants (Saint Bohaire), designed by Dr.Seidel herself, proved that it is possible to feed the drained beds (1st and 2nd stages), planted with reeds and alternately fed, with raw sewage at high loading rates without the occurence of clogging. However, it also showed that the last three stages, continuously fed, were not sufficiently oxygenated and clogged rapidly. This failure was also confirmed in Pont-Rémy although this plant is underloaded. The performance of the first stage beds could be improved further by the use of batch feeding (intermittent feeding), by increasing the height of the filter media and by choosing a more adequate granulometry. Alternately fed percolation flow beds can also be used as a first stage of treatment followed by wastewater stabilization ponds. The example of Gensac la Pallue shows that they can remove 85 % of the suspended solids and 70 % of the organic load, at a loading rate of 30 to 35 g of BOD₅ per square metre. Such a combined system can thus provide an efficient and reliable treatment requiring a specific surface reduced by 40 % as compared to wastewater stabilization ponds only.

KEYWORDS

Wastewater treatment; Reed beds; Percolation flow; Alternative feeding; Batch feeding; Gravel media; Wastewater stabilization ponds.

INTRODUCTION

"Rustic" and rather simple wastewater treatment systems for small communities in rural areas have been a major interest of CEMAGREF for a long time. CEMAGREF has largely contributed to the development of wastewater stabilization ponds (WSP). Today, there exist about 2000 WSP in rural France. However, WSP cannot be regarded as the solution in all cases. In particular, the surface required - in France, we calculate 10 m^2 for one p.e. - and the necessary tightness of the underlying soil might exclude the choice of WSP. Therefore CEMAGREF is also looking for alternatives to WSP, with the same degree of rusticity and simplicity in order to widen the choice for rural communities.

SAINT BOHAIRE (Loir et Cher)

For the reasons just mentioned, two small wastewater treatment plants at a boarding school, constructed in 1978 and 1982 under the direct advice of Dr. Seidel, attracted our attention. The first one not being very heavily loaded, it was especially the second plant which was of great experimental interest. It has been already described elsewhere (Boutin, 1987).

We will just recall here that it is a plant of a typical Seidel design (Fig. 1), with at first 2 percolation bed stages, the first stage being composed of 4 parallel and alternately fed beds and the second one of 2 parallel beds also alternately fed, all planted with Phragmites communis. Feeding time of each bed is 24 hours.

These first two stages are followed by 3 further horizontal-flow stages, each one consisting of one bed, which was thus being continuously fed. On the 3rd and 4th stages, the beds are planted with Scirpus lacustris, whereas the last bed is planted with Iris pseudacorus.
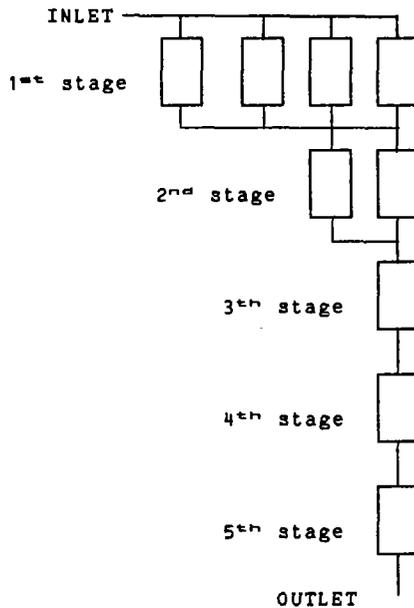

Fig. 1. Typical layout of a MPIP plant

TABLE 1   General Description of the Second
                Saint-Bohaire Plant

	TYPE OF FLOW	NUMBER OF BEDS	DIMENSION OF EACH BED			EMERGENT HYDROPHYTE Species
			Length (m)	Width (m)	Area (m²)	
1st Stage	Percolation	4 parallel	5.0	1.5	7.5	Phragmites communis
2nd Stage	Percolation	2 parallel	5.0	1.5	7.5	Phragmites communis
3rd Stage	Horizontal	1	4.0	1.5	6.0	Scirpus lacustris
4th Stage	Horizontal	1	4.0	1.5	6.0	Scirpus lacustris
5th Stage	Horizontal	1	4.0	1.5	6.0	Iris pseudacorus

The beds of the percolation stages are filled with a 45 cm high layer of
gravel, with an increasing granulometry from top to bottom (Fig. 2), whereas
the beds of the horizontal flow stages are filled by a uniform 30 cm of pea
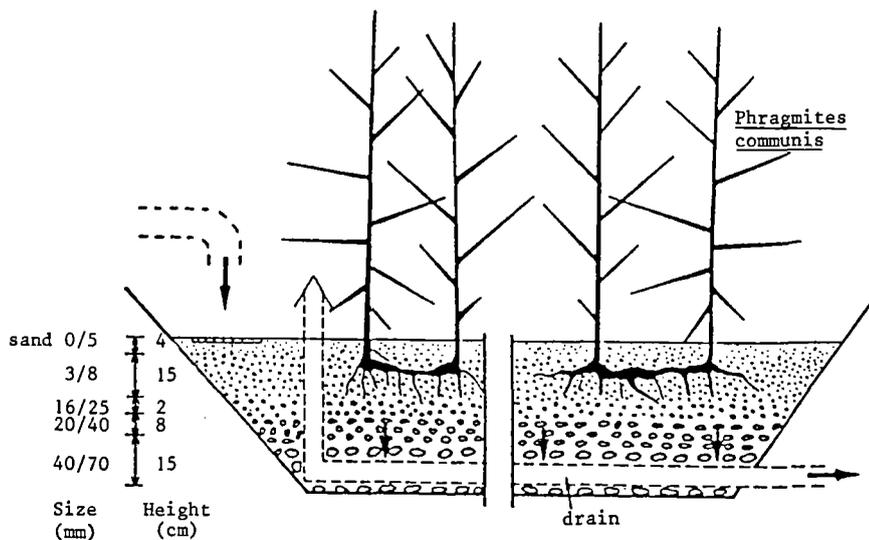gravel (Fig. 3).

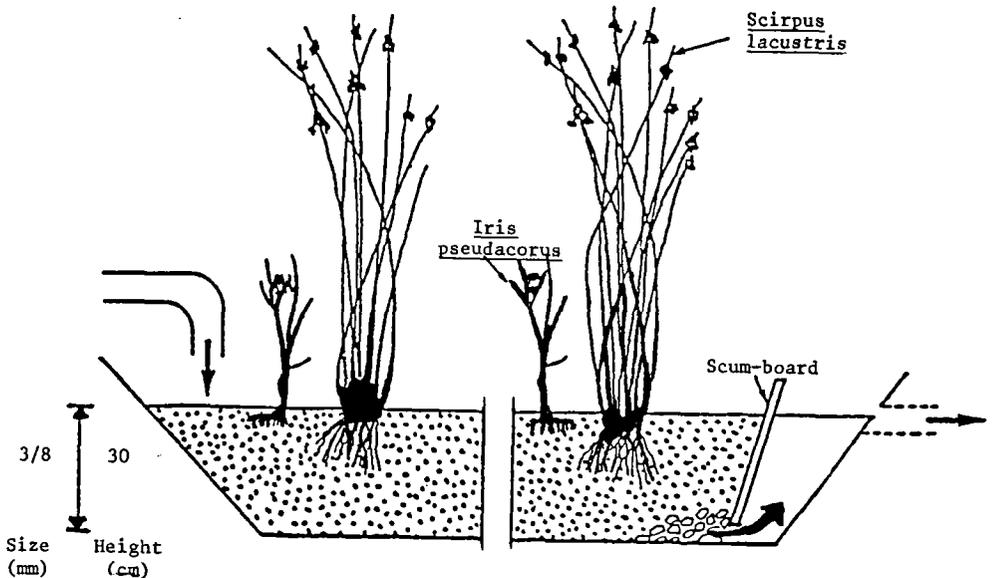Fig.2. Schematic cross section of a percolation flow bed.

Fig.3. Schematic cross section of an horizontal flow bed.

The size of the plant is 63 m² and our measuring has revealed a heavy organic and hydraulic loading during the time of school activities, but a light load is applied during week-ends and holidays. Mean organic loading was about (in g m^{-2} day^{-1}) :

    COD : 45   BOD₅ : 20   SS : 15
         KN : 3.8   TP : 0.9

Related to the total area of the four beds of the first stage (30 m²), the organic loading would be (in g m^{-2} day^{-1}) :

    COD : 94.5   BOD₅ : 42   SS : 31.5
         KN : 8.0   TP : 1.9

The mean hydraulic loading is 65 mm/day, which corresponds, according to our new definition (Pujol and Liénard, 1989) to about 2 m²/person equivalent for the entire surface area of the system.

On the basis of nine measuring campaigns, the mean abatements were :

    COD : 85%   BOD : 91 %   SS : 94 %
         KN : 45 %   TP : < 0 %

The monitoring of the plant also revealed a great efficiency of the 1ˢᵗ stage beds, which are able to accept very high loads of concentrated raw wastewater.

The second stage, however, was not as efficient, which we think is partly due to the fact that the suspended solids have already been retained on the 1st stage and the granulometry, being identical on the 2nd stage, does not permit a further filtration. The other reason is that the rather coarse gravel of the underlying layers has a relatively small specific surface for fixing active bacterial biomass.

The three last stages, always continuously fed, quickly showed signs of clogging, even though there were hardly any more suspended solids in the arriving wastewater. Samples of gravels taken out of these beds presented nauseous odours typical for an anaerobic environment ; organic matter was poorly mineralized and had a gelatinous aspect. Redox potential was always included between - 50 and + 100 mV/NHE. It is known from sand filter systems that bacteria in anaerobical conditions produce mucus slimes rich in polysaccharides (Kristiansen, 1981) which provoke the clogging mechanism by filling the macroporosity. This induces surface flow and consequently poor performance. But our first hypothesis was that this disfunctioning was mainly due to periodical overloading during winter time, when school activity is most important.

This incited us to construct a similar system on another site with more regular sewage inflow. Another reason for the construction of this new plant was the fact that we wanted to test longer feeding and rest periods on the first stages, and that this requires higher freeboards as some ponding occurs at the end of the feeding period (beds in Saint Bohaire are made of glassfibre which cannot be easily modified). We think that longer rest periods are necessary to achieve good mineralization of primary sludges. Last but not least, a new construction should also give us indications about the costs of building such a system.

PONT-REMY (Somme)

Pont-Rémy is thus almost a larger scale replica of the Saint Bohaire plant with its good and bad sides. However, for the first two upper layers of the percolation stages and for the horizontal flow stages the grain size was modified : we thought that a coarser upper layer of the percolation stages would facilitate drying and subsequent mineralization of the filtered primary sludges during rest periods and that coarser materials in the horizontal flow beds might prevent clogging. This plant has also already been briefly described elsewhere (Liénard, 1987).

Only half of the beds of the first two stages were put into operation, yet the loads applied per surface area of these beds are still lower than in Saint Bohaire due to a delay in the construction of the municipal sewerage system. The organic loads collected were respectively (in g m^{-2} day^{-1}) :

    COD : 18.2   BOD : 6.4   SS : 4.8
    NK : 2.2   TP : 0.5

The beds were fed for 48 hours (or 72 hours during weekends) which left a rest period of 7 days for the other 3 beds. We could not however determine wether the better mineralization of primary sludges in Pont-Rémy was due to these longer rest periods or due to the relatively low loads applied.

Two of the four beds in operation at the first stage were planted with Glyceria aquatica and one bed remained unplanted. Glyceria, although it showed a good second growth, proved to be ill-adapted due to growth in dense clusters and poor surface colonization. The unplanted bed showed long periods of ponding, but we could not measure any differences in treatment efficiency with our limited investigations on this aspect. The Phragmites from natural wetlands planted in small clumps into one of the beds in April 87 developed well and the infiltration surface in this bed has the best aspect and shows no signs of clogging. Earlier plantings from seedlings bought from an horticulturist were not successful in the coarse material of the beds.

On the second stage the treatment efficiency was low again, because we repeated the same error made in Saint Bohaire, that is not to choose a finer filling material on the second stage beds than on the first stage beds. The absence of the filter effect of disposed primary sludge causes very rapid infiltration on these beds, using only 40 to 60 % of their surface area.

On the last stages, the same clogging problems as in Saint Bohaire occurred soon, even in the absence of high loading peaks. We tried to improve the aeration of these beds by installing siphons on the outflow, in order to drain the beds in intervals related to the flow. However, due to the topography, we could not create a hydraulic gradient sufficient to empty the beds significantly. In Saint Bohaire, we later installed similar siphons; we noticed an increased oxygenation of the media but nevertheless apparently this was insufficient to prevent clogging. Most likely, a complete drying of the beds is needed. Maybe the roots of Scirpus have a clogging effect as well.

The production of plant biomass on these last stages is very important and necessitates biannual cutting, if one wants to prevent pollution by decaying organic matter. The supplementary management constraint of biannual cutting has no advantage for the elimination of nutrients, as quantities exported with the plant biomass are negligible compared to the loads applied in such systems.

Based on one complete measurement campaign of 48 hours during the summer season, the abatement of pollution was as follows:

COD : 82 %   BOD₅ : 87 %   SS : 98 %
    NK : 66 %   TP : < 0 %

Random samples were taken regularly by qualified staff. The effluent quality was always satisfactory. However, we are inclined to think that the ill-functioning of the last three stages would have had a more marked negative influence, had the plant been fed at its full permissible load with all beds in operation on the first two stages.

Construction costs of the Pont-Rémy plant were, in 1986 : 1650 FF /p.e., considering that reinforced concrete beds were chosen.

GENSAC LA PALLUE (Charente)

The small township of Gensac la Pallue (1700 inhabitants) had to extend its original treatment facilities composed of two wastewater stabilization ponds while being limited by available space. This was the opportunity for us to propose a first step of treatment by reed beds. For dimensioning these beds we used the loads applied to the first stage of the second plant in Saint Bohaire. Thus, we were able to test the performance of such beds under high but regular loading. For topographical reasons and in order to achieve a good surface distribution through a high instantaneous hydraulic load, we chose 8 parallel beds in one stage (Fig. 4). Also a third polishing pond was added.
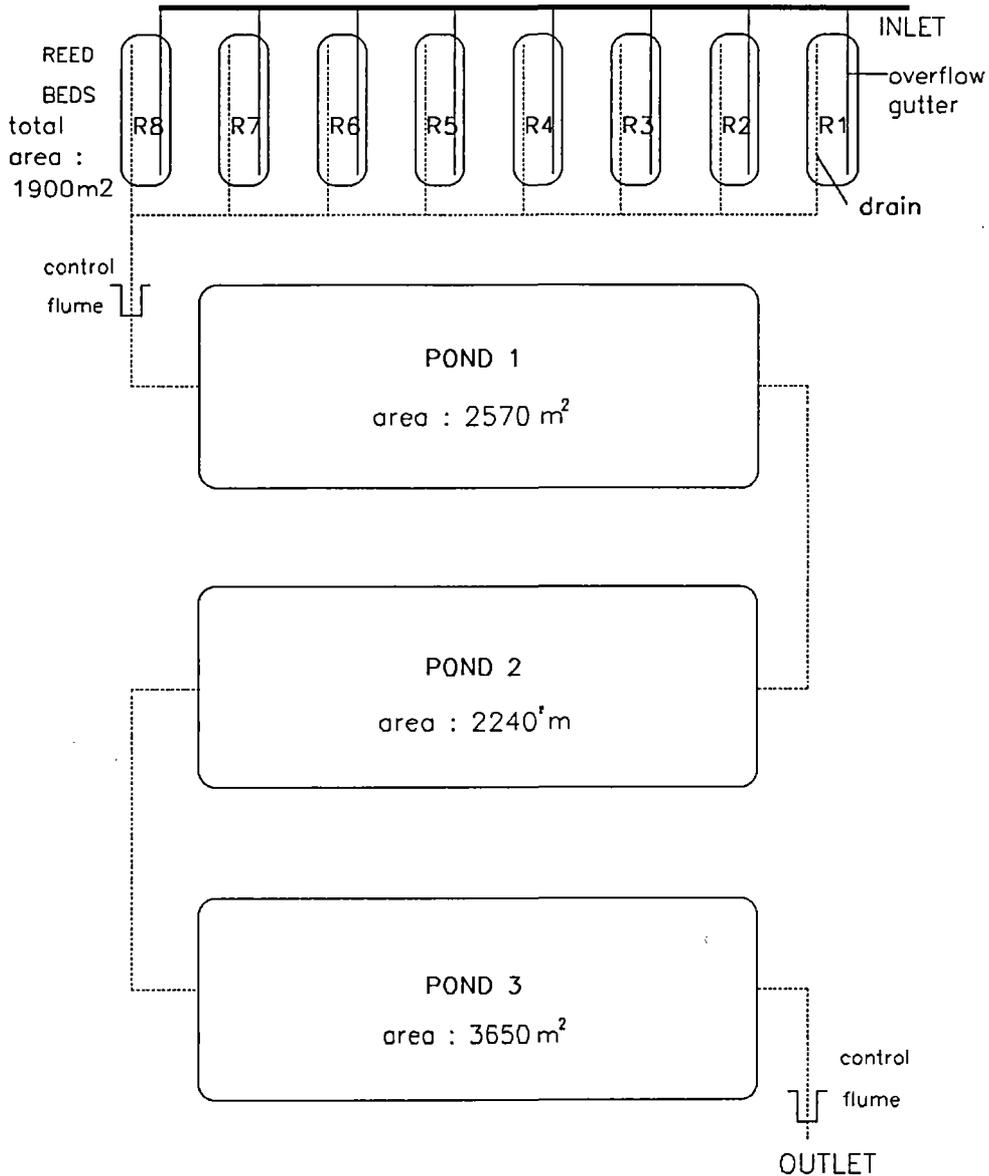
REED
BEDS
total
area :
1900m2

R8 R7 R6 R5 R4 R3 R2 R1

INLET

overflow
gutter

drain

control
flume

POND 1

area : 2570 m^2

POND 2

area : 2240'm

POND 3

area : 3650 m^2

control

flume

OUTLET

Fig. 4. Schematic description of the Gensac plant.

This allowed a total dimensioning of approximately 6 m^2 p.e.$^{-1}$:

    - about 1 m^2 p.e.$^{-1}$ for the reed filters ;
    - and about 5 m^2 p.e.$^{-1}$ for the WSP (instead of 10 m^2
normally required).

The watertightness of the reed filters was achieved by puddled clay, found in
the vicinity. The granulometry of the filling is identical with that in Saint
Bohaire, except that there is no first upper layer of sand. As mentioned
before, we think that a coarser material will improve the drying of the primary
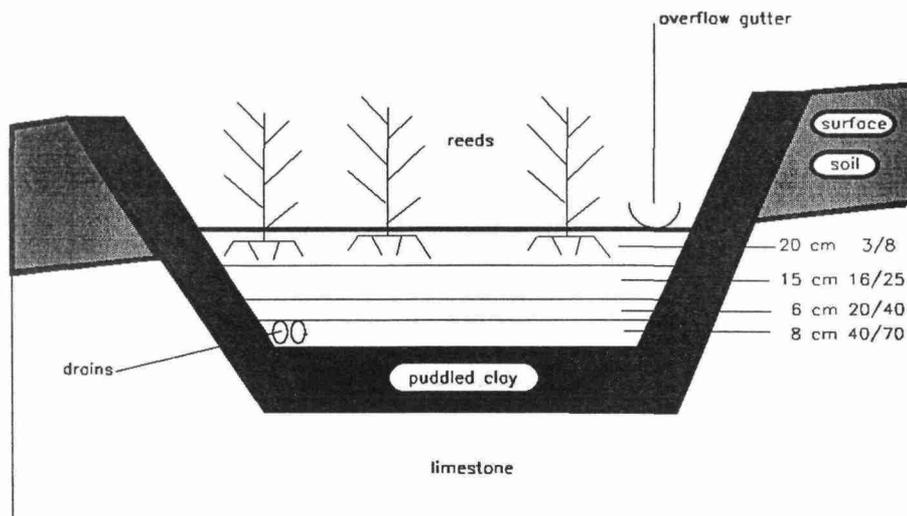sludge. The total height of the beds is about 50 cm (Fig. 5).

Fig. 5.   Schematic cross section of a reed bed in Gensac.

The feeding of the beds is for 24 hour periods (72 hours during weekends). The
rest period was thus 9 days and each bed is fed during the weekends
alternatively once in 8 weeks.

Since June 1987, the loads applied are as follows (in kg d^{-1}) :

    COD : 122.4   BOD : 41.7   SS : 58.7
        KN : 10.0   TP : 2.8

Based on the total   area of the reed beds, this represents the following loads
(in g m^{-2}) :

    COD : 64.4   BOD : 22.0   SS : 30.9
        KN : 5.3   TP : 1.5

The   change in   the concentrations is shown on Table 2.

TABLE 2   Change in the Concentrations (mg * l^{-1})

	Raw influent	Reed bed effl.	Final effluent
COD	720 (554-820) (6)	245 (92-400) (14)	75 (48-128) (10)
BOD	245 (210-280) (4)	77 (35-155) (9)	11 (6-16) (6)
SS	345 (310-392) (6)	50 (20-123) (14)	11 (<5-20) (10)
KN	58.5 (35-80) (6)	54.2 (21.5-69) (13)	26.4 (15-51) (9)
TP	16.7 (13-22) (6)	11.8 (5.3-18.0) (11)	6.4 (4.25-10.5) (5)

                    ( ) : number of samples
                    (min value - max value)
        The performance of the reed beds is given in Table 3.

TABLE 3 Elimination on Reed Beds in %

	September 88		March 89		June 89		Mean
COD	66	68	77	66	67	67	68
BOD	68	70	74	-	70	-	70
SS	87	84	87	84	86	86	85

KN	20	20	31	25	36	43
TP	34	4	25	16	26	31

We observed little variation in the removal of COD, BOD₃ and SS but a high variability in the removal of total phosphorus and Kjeldahl nitrogen.

In April 1989, we also measured the bacteriological elimination of the treatment plant in Gensac, the results are given on Table 4 (in units per 100 ml).

TABLE 4 Bacteriological Elimination

	Raw Influent	After reed beds		Effluent after ponds
		Bed working	Bed working the day before	
Faecal coliforms	6.4×10^4	5.4×10^4	3.0×10^4	$< 10^3$
Faecal strepto-coccus	3.3×10^4	1.5×10^4	2.8×10^4	$< 10^2$

The functioning of Gensac la Pallue showed that these type of beds are able to receive rather concentrated raw wastewater without clogging. Together with the ponds, a satisfactory effluent quality was attained. Nitrogen and phosphorus retention on the reed beds was however low, although partly compensated by the ponds. Suspended solids (algae) in the final effluent were very low for wastewater stabilization ponds due to the proliferation of Daphnia in the last pond, during a large period of the year. It has been proved that this type of treatment facility can be an adapted solution to improve the performance of overloaded ponds.

The total time needed for the maintenance of reed beds and ponds did not exceed 30 days per year. At present we are testing if we can reduce this further by doing away with the cutting of the reeds, which accounts for 8 days per year.

SAINT SYMPHORIEN DE LAY (Loire)

This plant is a sand filter consisting of 2 alternating beds fed with influent settled in primary sedimentation ponds. The height of the sand beds is 1.7 m and the beds were fed in weekly intervals.

Although not being a macrophyte bed Saint Symphorien allowed us to understand the importance of intermittent or batch feeding.

We will not go into details about this plant, but just briefly present the improvement of treatment efficiency brought about by the introduction of batch feeding (Table 5).

TABLE 5   Treatment Efficiency at Saint Symphorien

in %	Before batch feeding	After batch feeding
COD	62.0	82.5
SS	56.0	92.0
TN	10.5	74.7
TP	10.4	77.0

(respectively 5th and 6th day of the cycle).

This shows that not only the COD abatement can be significantly increased but also nitrification can be attained. More surprisingly, phosphorus retention can also be improved, provided an adequate substrate is chosen. Increased suspended solids retention is more difficult to explain.

This experience incited us to use batch feeding on the 1st stage of macrophyte beds in the future.

CONCLUSIONS

The reed bed systems monitored by CEMAGREF show that it is possible to treat screened raw sewage on the first stage with a specific load of about 30 - 35 g of BOD₅ per square metre per day, without clogging. However, the beds have to be well drained and alternately fed. A rest period of seven days seems to be necessary in order to achieve a good mineralization of the filtered primary sludges. An elimination of 85 % of SS and 70 % of the organic load is attained. Most likely, their performance can be further improved by batch feeding.

We think that the suspended solids held back from the raw sewage on the infiltration surface actually improve the filtration capacity and the microbiological activity on the well oxygenated surface of the reed beds. The reeds protect this microbiological activity from the negative effects of U.V. light and rapid desiccation in summer and, to a lesser degree, of frost in winter.

The horizontal flow beds which are continuously fed did not have a high efficiency and clogged rather rapidly. In future plants, we will abolish them and limit the new design to two stages of alternately fed percolation beds, all planted with reeds.

We also think to put pea gravel on the surface of the first stage beds and to decrease the granulometry of the lower layers as well as of the second stage beds and to increase the height of the beds.

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